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**CHICKPEA SEED SIZE AND SEED QUALITY
RELATIONSHIPS**

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FINAL REPORT
CHICKPEA SEED SIZE AND SEED QUALITY RELATIONSHIPS

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ABSTRACT

The nutritional content of chickpea (*Cicer arietinum* L.) seed may be related to seed size, uniformity, cooking characteristics and moisture uptake for processing. The goal of the project is to quantify yield components and yield quality in chickpea genotypes which vary in seed-size. Field plots were seeded in late May 2002 and 2003 at two Saskatchewan locations, Saskatoon and Swift Current; seed yield was collected and nutrient contents measured.

Oil concentration was between 4 to 6.5% in the genotypes; low fat gives rise to poor taste characteristics. Largest seeded genotypes were CDC Diva, CDC Xena and CDC Yuma in both years. Small seeded genotypes were CDC Desiray, CDC Anna and Myles. A differential in drought increased protein in 2003 at Saskatoon. Increasing seed size tended to increase protein concentration in a well-watered year, a positive finding for markets based on larger seed size. Effects of drought increased seed protein (>26%) far more than genotype or seed size class (18.4 to 19.7%), and protein concentrations tended to be high (> 26%) across the whole range of 51 to 700 mg seed size. Starch ranged from 34% to 401%. Large sized seed, and particularly Kabuli chickpea, had higher starch concentrations. Seed coat thickness appeared to be associated with market class, the Desi types had colored seed coats and thicker seed coats. As seed size increased, seed had thinner coats. In drought, seed had thinner coats but the same pattern of small seed having the thicker coats was still evident. Fiber ranged from 49 to 64%, which is likely an over estimation. Higher fiber was found in Desi genotypes; lower fiber (< 58% NDF and <56% ADF) was found in Kabuli genotypes. Low fiber can be selected for by choosing large seed and the Kabuli market class. Water imbibition, or uptake into a seed, was quantified by two models: the Peleg model and a monomolecular model. Larger seed were more effective at water uptake, and imbibed water at higher rates than their small seeded counterparts. Because most of the small seeded genotypes were Kabuli, we are not able to say if the water uptake is related specifically to market class or seed size, since both are correlated in our treatment choices. For the initial rate of water uptake, seed with size >300 mg had the greater rates of uptake. Lower rates of water uptake were seen for small seed sizes. Of interest were the same rates of water taken up by a wide range of seed in the size category 300 to 700 mg.

This data set from two locations and two years has an excellent range of genetic material, and extensive seed size classification and yield measurement. Findings will be used by the CDC to breed chickpea cultivars based on quality, and results will also be of benefit to the processing and marketing industries. Large seed size has higher protein and fat, starch and lower fiber. Large sized seed rapidly takes up water for seedling vigor and food processing. We believe chickpea has tremendous potential for improved grain quality and improved nutritional value.

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EXECUTIVE SUMMARY

Project objectives

The goal of the project was to quantify yield components and yield quality in chickpea genotypes that vary in seed-size. Specific objectives were:

1. Identify genotypic variation for the yield components of seed size and final yield.
2. Identify and quantify associations between seed size and nutritional content of the seed.
3. Quantify the relative importance of yield components of small-seeded versus large-seeded genotypes and select appropriate strategies for a chickpea system having a specific seed-size category with yield quantity and quality.
4. Classify and quantify seed-size uniformity for ease of processing by the seed and food industry.
5. Investigate how the seed coat thickness varies with changes in seed size and nutritional content.

Methods

Summer 2002 pilot study

Aim: to investigate the contribution of seed size and genotype to protein concentration for 10 chickpea genotypes. This study was done on 2001-grown bulk seed (used for seeding 2002 field plots) while the 2002 field study was growing.

The 10 genotypes used were:

Kabuli types

CDC Chico 265 mg seed⁻¹

CDC Diva 490 mg seed⁻¹

CDC Xena 470 mg seed⁻¹

CDC Yuma 410 mg seed⁻¹

Desi types

92-073-40 (from the CDC breeding program) 370mg seed⁻¹

CDC Anna 220 mg seed⁻¹

Amit (formerly known as B-90) 265 mg seed⁻¹

CDC Desiray 200 mg seed⁻¹

Myles 200 mg seed⁻¹

CDC Nika 330 mg seed⁻¹

The seed-size distribution of each genotype was measured by weighing individually 100 seed taken at random from the bulk seed supply. For measuring the seed-size classes, 15 g of seed size of seed for each genotype was collected where seed fell into each of 25mg seed-size classes present for that genotype. For example, seed of a particular genotype was separated by weight into the 101 to 125 mg class, the 126 to 150 mg class, the 151 to 175 mg class etc. Oil concentration (% by weight) in this report was extracted with hexane. Treatments were replicated three times.

Summer 2002 and 2003 field study.

The above 10 chickpea genotypes varying in seed size and seed number per pod were seeded in late May, 2002 and 2003 at two locations, Saskatoon and Swift Current. The experiments were designed as a randomized complete block Designs with four replications, at both locations for each of the two years. Seed was harvested for each plot in October. A randomly selected sample of seed, about 400g, was taken from combined seed for each plot. The seed-size distribution of each genotype was measured for each plot by weighing individually 100 seed taken at random from the bulk seed of each plot. For measuring the seed-size classes, 15 g of seed for each seed size class for each plot was collected - seed fell into each of 25mg seed-size classes present for that genotype. For example, seed of a particular genotype was separated by weight into the 101 to 125 mg class, the 126 to 150 mg class, the 151 to 175 mg class etc. Protein (% by weight) was measured on full sample, and each seed size sample for each plot.

Measurements taken were:

- final yield,
- seed-size categories at maturity for each genotype,
- nitrogen and protein analysis by combustion,
- Near Infra Red Spectroscopy scans (for starch prediction),
- acid-detergent fiber (ADF) and neutral-detergent fiber (NDF) by Ankom methodology,
- starch is a three stage enzyme digestion,
- seed coat thickness by direct measurement with calipers,
- water uptake by seed

Results and Conclusions

The summer field season in 2002 started as dry and cool, drought, followed by a cool wet grain-fill period. Seed in Saskatoon was smaller and of lower quality than seed from Swift Current; immature or cracked seed was sorted out and discarded. The 2003 field season started with more moisture than 2002, but the season ended early due to drought and high temperature. Seed from Saskatoon were smaller than that from Swift Current because Saskatoon received less seasonal moisture in 2003.

Pilot study

- Oil concentration differed significantly according to genotype with the highest oil concentrations were found in CDC Nika, CDC Diva and 92-073-40 (about 5.4 to 6.5%).
- Chickpea selected for large seed or larger seed size classes per genotype would also contain more oil than small seeded chickpea, but the range from the genotypes tested was small, about 4 to 6.5%; low fat gives rise to poor taste characteristics.

Field study 2002 and 2003

- Largest seeded genotypes were CDC Diva, CDC Xena and CDC Yuma in both years. Small seeded genotypes were CDC Desiray, CDC Anna and Myles. Tight or narrow seed size distributions were evident for CDC Desiray, CDC Diva and Myles in 2002, and CDC Chico, CDC Diva, CDC Yuma and CDC Xena in 2003.
- Two genotypes, CDC Anna and Amit, had seed size distributions with unequal tailing to the left meaning more small-sized seed classes. Distribution towards more larger sized seed classes in 2003 was limited by drought.
- Protein concentration in genotypes differed significantly.
- Chickpea from Saskatoon and Swift Current had similar protein concentrations in 2002, but a differential in drought increased protein in 2003, particularly at Saskatoon. These protein differences were most likely associated with weather experienced during late seed filling when metabolism may be affected (protein and starch deposition) and seed size (determined by cell expansion) has already been completed.
- Larger seed had significantly higher protein compared to smaller seed.

- Increasing seed size tended to increase protein concentration in a well-watered year, a positive finding for markets based on larger seed size. Selection of chickpea for large seed would also have higher protein concentration.
- However, the effects of drought increased seed protein (>26%) far more than genotype or seed size class (18.4 to 19.7%), and protein concentrations tended to be high (> 26% across the whole range of 51 to 700 mg seed size).
- Myles was unique in that it was both small seeded (<350 mg) and had high protein (19.4 to 23.3%). CDC Xena and CDC Yuma had consistently high protein across the range of seed size.
- Seed marketing and sourcing for high protein seed will be most effective by selecting seed that has been grown under dry or drought conditions, although seed may be slightly smaller compared to seed sourced from well-watered years.
- Starch ranged from 34.2% to 40.7% using the wet chemistry enzyme protocol.
- Starch in 2002 differed significantly according to genotype, with highest starch concentration found in Amit, CDC Chico, CDC Diva, CDC Xena and CDC Yuma (> 36.9%). Lower starch was found in the remaining genotypes, with CDC Anna having the least (34.2%). Selecting for large seed does not reduce starch or protein concentration.
- Large sized seed, and particularly Kabuli chickpea, had the larger starch concentrations.
- A prediction equation using Near Infra Red Spectroscopy can now be built because all samples have been scanned into the NIR.
- Seed coat thickness differed according to genotype, with the thickest coats (0.15 to 0.20 mm) found in Desi chickpea (CDC Anna, CDC Desiray, Myles and CDC Nika). Thinner coats (0.08 to 0.09 mm) were found in the Kabuli genotypes (CDC Chico, CDC Diva, CDC Xena and CDC Yuma).
- Seed coat thickness appears to be associated with market class, the Desi types having colored seed coats and thicker seed coats. As seed size increased, seed had thinner coats. In dry years, seed had thinner coats but the same pattern of small seed having the thicker coats was still evident.
- The range in fiber was 49 to 64% for all data using the Ankom methods, which is a gross over estimation in chickpea from an expected 10 to 15% range for crude fiber. The reason for fiber overestimation by ADF and NDF methods is not solved at this time

- Higher concentrations of fiber (both NDF at $> 62\%$ and ADF at $>60\%$) were found in the Desi genotypes, namely 92-073-40, CDC Desiray, and Myles.
- Lower concentrations of fiber ($< 58\%$ NDF and $<56\%$ ADF) were found in Kabuli genotypes.
- Small seed in the range of 50 to 250 mg had fiber concentrations in the range of 55 to 63%, regardless of ADF or NDF method. Larger seeds, in the range of 400 to 700 mg had lower fiber concentrations, typically in the range of 49 to 55%. Small seeds did have higher fiber concentrations, reflecting the Desi colored seed coat, and the higher surface area to volume ratio from a fixed weight of seed (one gram of small seed will have more seed coat than one gram of large seed). Low fiber can be selected for by choosing large seed and the Kabuli market class.
- Water imbibition, or uptake into a seed, was quantified by two models, the Peleg model and a monomolecular model. The Peleg is a reciprocal model; the monomolecular model illustrates a sharp initial uptake, which plateaus off. The Peleg model allowed us to separate, quantitatively, the ability of seed to take up water. Larger seed are more effective at water uptake, and take up water at higher rates than their small seeded counterparts. Because most of the small seeded genotypes were Kabuli, we are not able to say if the water uptake is specifically related to market class or seed size, since both are correlated in our treatment choices.
- Small seeded genotypes (<200 mg) had intercepts that were highest indicating lower amounts of moisture present. Slope values were highest for the small seeded, and lowest for the large seeded (>300 mg). Seed sizes with small slopes meant that such seeds took up water the most rapidly.
- The Monomolecular model identified the same patterns in genotypes as the Peleg model. The Monomolecular coefficients 'a' and 'b' measure different parameters, 'a' being the final amount of water taken up by eight seed, and 'b' being the initial rate of water uptake (slope of the curve).
- Small seeded chickpea <375 mg, had lower final water taken up ('a' coefficient). Larger seeded chickpea > 500 mg had high rates of water taken up, from 4.9 to 5.7 g for eight seed.
- For initial rate of water uptake, seed with size >300 mg had the greater rates of uptake. Lower rates of water uptake were seen for small seed sizes. Of interest are the same rates of water taken up by a wide range of seed in the size category 300 to 700 mg.

Progress and Implications

We have a data set with two locations, an excellent range of genetic material, and extensive seed size classification and yield measurement. These data have come from drought years, although plots at Swift Current in 2002 were excellent and yielded well. The data set has breadth in structure, clear patterns between seed size category and quality measurements are emerging, and many findings are very interesting and positive. Findings will be used by the CDC to breed chickpea cultivars based on quality, and results will also be of great benefit to the processing and marketing industries. Large seed size has higher protein and fat, starch and lower fiber. Large sized seed rapidly takes up water for seedling vigor and food processing. We believe chickpea has tremendous potential for improved grain quality and improved nutritional value.

TECHNICAL REPORT

Background

Seed size and seed number are directly associated with yield. The nutritional content of seed may be related to seed size, uniformity, cooking characteristics and moisture uptake for processing. Small seeds would be expected to have a higher seed coat to cotyledon ratio, resulting in possible increased fiber and decreased protein and starch. We aim to investigate seed size of chickpea cultivars for enhanced nutritional quality. In understanding seed size and seed quality components in a range of chickpea genotypes that vary in seed size, we will be able to select better chickpea cultivars for seed quality end uses. Such information linking nutritional content and seed coat thickness to seed size is lacking for chickpea breeding material.

Expected Results

We will identify and quantify the following:

- the variation for yield, seed size and seed quality (protein, starch and fiber) for a range of chickpea cultivars.
- the relationship between seed size and seed quality components of crude protein, starch and fiber.

- how the nutritional content of seed varies according to seed size and size uniformity inherent to a genotype.
- if quality and uniformity depend on seed size.

Finally we will develop a strategy to breed for a specific seed size while maintaining yield and the improved seed quality traits for food processing and niche markets. Uniformity of seed will be knowledge that is transferable to the processing industry.

Goal of project:

To understand and quantify the various components making up yield and seed quality characteristics in chickpea genotypes, which vary in seed-size.

Project objectives:

1. Identify genotypic variation for the yield components of seed size, and final yield.
 2. Identify and quantify associations between seed size and nutritional content of the seed.
 3. Quantify the relative importance of yield components of small-seeded versus large-seeded genotypes and select appropriate strategies for a chickpea system having a specific seed-size category with yield quantity and quality.
 4. Classify and quantify seed-size uniformity for ease of processing by the seed and food industry.
 5. Investigate how the seed coat thickness varies with changes in seed size and nutritional content.
- Does seed size and seed coat thickness affect the rate of water imbibed by a seed?

Materials and Methods

Year 1 of the study started in the 2002 field season. The second and final year was the 2003 field season. Ten chickpea genotypes used in experiments were both Kabuli and Desi types, with variation in seed size. The Kabuli types were CDC Yuma (410 mg seed⁻¹); CDC Xena (470 mg seed⁻¹); CDC Diva (490 mg seed⁻¹); CDC Chico (265 mg seed⁻¹). The Desi types were Amit (formerly known as B-90; 265 mg seed⁻¹); Myles and CDC Desiray (both 200 mg seed⁻¹); CDC Anna (220 mg seed⁻¹); CDC Nika (330 mg seed⁻¹). One genotype from the CDC breeding program, 92-073-40 (a Desi type; 370 mg seed⁻¹) with a larger

proportion of double pods than normal cultivars, was used in the 2002 field study to represent double-podded chickpea because sufficient seed was available. Seed increase of genotypes was done as needed.

Experimental Design: randomized block Design (RBD) at two locations, 2002 and 2003: 4 blocks x 10 cultivars = 40 plots per location.

Statistical Analysis: univariate analysis of variance for yield and seed size.

In 2001, a pilot study using bulk seed of the 10 genotypes had seed size, oil and protein measurements.

For the 2002 and 2003 field studies, data were taken on a subsample of seed from each plot for a range of seed size. (1) A randomly selected sample of seed of about 400 mg, referred to as a full sample, was taken from combined seed for each plot. (2) The seed-size distribution of each genotype was measured for each plot by weighing individually 100 seed taken at random from the bulk seed of each plot. (3) For measuring the seed-size classes, 15 g of seed for each seed size class for each plot was collected - seed fell into each of 25mg seed-size classes present for that genotype. For example, seed of a particular genotype was separated by weight into the 101 to 125 mg class, the 126 to 150 mg class, the 151 to 175 mg class etc. In 2003, seed yield was low due to heat and drought, so the more limited seed was separated into 50 mg size classes.

The seed, as a full sample (1), or as seed size categories (3) for each plot was then ground for the following measurements.

- Crude protein (by Leco nitrogen combustion), starch (by a three stage alpha amylase enzyme digestion, with amyloglucosidase and peroxidase-glucose oxidase), acid-detergent fiber (ADF) and neutral-detergent fiber (NDF) by wet chemistry (Ankom fiber digestion). Oil concentration by hexane extraction was done on pilot samples only.
- Seed coat thickness was measured directly using calipers.
- The ability of chickpea seed to imbibe water was measured on eight seed per sample by water uptake (Hung et al, 1993, J. Food Sci. 58:848) at 0, 2, 4, 6, 8, 12 and 24 hours. The Peleg model (a statistical reciprocal model) and a monomolecular model were fitted in SAS version 8.2 (SAS Institute, 2000) on the seed water uptake data. Data was modelled on eight seed per sample.
- Peleg model: y axis was hours divided by water uptake at a specific time; the x axis was time from 0 to 24 hours. $Y = \text{slope} \cdot \text{time} + \text{intercept}$. A low slope value means that water imbibition is rapid. The intercept appears to correspond with the seeds' initial water content.

- Monomolecular model: y axis was water uptake; x axis was time from 0 to 24 hours.

$$Y = a \times [1 - \exp(-1 \times b \times \text{time})]$$
 where 'a' is the plateau or maximum water taken up, and 'b' is the initial slope or rate of water uptake. A high 'a' coefficient means the seed took up much water, and a high slope value 'b' means that the rate of water imbibition initially into the seed was high.

Results and Discussion

Oil concentration for the 2001 pilot study

- Oil concentration differed significantly according to genotype (Table 1).
- Highest oil concentrations were found in CDC Nika, CDC Diva and 92-073-40 (about 5.4 to 6.5%).
- Lowest oil concentrations were found in CDC Anna, CDC Desiray and Myles (about 4.5 to 4.6%).
- As seed size class increased, oil concentration increased significantly (Table 2).
- Generally, larger seed size classes (>600 mg) had higher oil concentration than mid range classes (300 to 475 mg); smaller classes (<300 mg) had lower oil concentration.
- Chickpea selected for large seed or larger seed size classes per genotype should therefore contain more oil than small seeded chickpea, but the range was small, about 4 to 6.5%.
- Genotype also interacted with seed size class (data not shown). Three patterns were evident, the main one was as seed size increased, oil concentration increased. The second was no change in oil for increasing size class (92-073-40 only). The third pattern, seen in two genotypes (CDC Anna and CDC Diva), was little difference in seed size class across the range except for the largest and smallest size classes. CDC Diva and 92-073-40 had the highest oil concentrations across their seed size range.

Seed size distribution for 2002 and 2003

- Using the mean seed weight from each plot of the 2002 and 2003 field studies, seed size differed significantly according to genotype (Tables 3 and 4).

- Mean seed weight did not change significantly with location in 2002, but did in 2003. In 2003, the Saskatoon location was drier than Swift Current, and the season ended early. Drought during mid seed-fill caused Saskatoon seed size to be significantly smaller than Swift Current seed (Table 5). CDC Anna and CDC Chico seed were the same at both locations, but all other genotypes had smaller seed (about 30 mg less) at Saskatoon.
- Largest seeded genotypes were CDC Diva, CDC Xena and CDC Yuma in both years. Small seeded genotypes were CDC Desiray, CDC Anna and Myles, with Myles being the smallest (Tables 3 and 4).
- Seed size distributions that were skewed to the left (positive skewness) were CDC Anna, Amit and CDC Chico in 2002 (Table 3). In 2003, CDC Anna, and to a lesser extent, CDC Desiray, exhibited a seed size distribution that was skewed to the left (Table 4). Other genotypes had seed sizes that were more normally distributed, but in 2003, CDC Xena was skewed moderately to the right.
- Two genotypes, CDC Anna and Amit, had seed size distribution with unequal tailing to the left in 2002, meaning more small-sized seed classes. In 2003, again CDC Anna showed the same tendency, along with CDC Desiray, for more small-sized seed classes.
- Genotypes with unequal tailing of seed size classes to the right were CDC Yuma and 92-073-40 in 2002 only. These genotypes had more large-sized seed classes. Distribution towards more larger sized seed classes in 2003 was limited by drought.
- Tight or narrow seed size distributions were evident for CDC Desiray, CDC Diva and Myles in 2002, and CDC Chico, CDC Diva, CDC Yuma and CDC Xena in 2003 (Tables 3 and 4).

Protein concentration for 2002 and 2003

- Protein concentration was first assessed from full samples (Tables 5 and 6). The range of protein fits within the 15 to 30 range reported by Hulse for chickpea (*Hulse, J.H., Nature, Composition and Utilization of Food Legumes. In Expanding the Production and Use of Cool season Food Legumes 77-87, Eds Muehlbauer and Kaiser, Luwer Academic Publishers, Dordrecht, 1994*).
- Protein concentration in genotypes differed significantly (Table 5).
- Chickpea from Saskatoon and Swift Current had similar protein concentrations in 2002, but a differential in drought increased protein in 2003, and most markedly increased protein in seed from Saskatoon compared to seed from Swift Current. Data for both years and sites combined showed that Saskatoon had higher protein (23.2%) compared to Swift Current (20.7%), and that protein in 2003 was 27.1% compared to 18.8% in 2002. Drought increased accumulation of protein in seed,

these seed also being slightly smaller compared to a well-watered year. These protein differences were most likely associated with weather experienced during late seed filling when metabolism may be affected (protein and starch deposition) and seed size (determined by cell expansion) had already been completed.

- Location and genotype interactions for protein concentration were not significant in 2002, but were in 2003.
- Highest protein concentrations were found in CDC Chico, CDC Diva, Myles, CDC Xena and CDC Yuma (Table 5).
- Lowest protein concentrations were found in 92-073-40 and Amit, which were only seeded in 2002, and also CDC Anna (Table 6).
- Highest protein concentration was not associated with large seed size - Myles had the highest protein (23.4%) but also the smallest seed size (184 to 193 mg; Tables 3 and 4). In fact, for both years combined, CDC Chico, Myles, CDC Xena and CDC Yuma had similar and high protein concentrations, yet seed covered a wide range in size.
- Table 7 shows results from analyzing seed size class. The analysis was statistically unbalanced because not all classes are represented for all genotype. However, several findings were drawn.
- Seed size classes differed significantly, with larger seed tending to have having higher protein compared to smaller seed (Table 7).
- Increasing seed size tended to increase protein concentration in a well-watered year, a positive finding for markets based on larger seed size. Selection of chickpea for large seed would also have higher protein concentration.
- However, the effects of drought increased seed protein (>26%) far more than genotype or seed size class (18.4 to 19.7%), and protein concentrations tended to be high (> 26%) across the whole range of 51 to 700 mg seed size.
- For interactions between genotype and seed-size class, significant differences were evident in 2002 and 2003 (Tables 8 and 9).
- In 2002, CDC Anna had consistently lower protein, while CDC Diva, Myles, CDC Xena and CDC Yuma had high protein concentration (Table 8). As size increased, protein increased for CDC Diva and Myles. Myles is unique in that it is small seeded (<350 mg), but has high protein (19.4 to 23.3%). CDC Anna has a similar range of seed size, but low protein (<18.2%). CDC Xena and CDC Yuma had consistently high protein across the range of seed size.
- In the dry year of 2003, lowest protein across seed size classes was seen in CDC Anna and CDC Desiray (Table 9). CDC Chico, CDC Diva, Myles and CDC Xena tended to have a high protein (24

to 28.5%) across their range. CDC Nika had variable protein. CDC Yuma had consistently the highest amount of protein measured (27 to 30%), and the concentrations were consistent for 151 to 600 mg seed.

- Seed marketing and sourcing for high protein seed is most effective by selecting seed that has been grown under dry drought conditions, although seed may be slightly smaller compared to seed sourced from well-watered years.

Starch concentration for 2002

- In 2002, starch ranged from 34.2% to 40.7% using the wet chemistry enzyme protocol. This is in range with chickpea starch reported by Hulse in 1994 of 37 to 50% (*Hulse, J.H., Nature, Composition and Utilization of Food Legumes. In Expanding the Production and Use of Cool season Food Legumes 77-87, Eds Muehlbauer and Kaiser, Luwer Academic Publishers, Dordrecht, 1994*).
- Starch in 2002 differed significantly according to genotype, with highest starch concentration found in Amit, CDC Chico, CDC Diva, CDC Xena and CDC Yuma (> 36.9%). Lower starch was found in the remaining genotypes, with CDC Anna having the least (34.2%).
- For individual seed size classes, seed greater than 400 mg had higher concentrations of starch (> 37%). Although smaller seed sometimes had starch at about 37%, the two smallest size classes of <200 mg had significantly lower starch concentrations of 33.8% or less in 2002.
- Large sized seed, and particularly Kabuli chickpea, have the larger starch concentrations.
- Starch has not been measured for 2003 because of problems sourcing enzyme and budget limitations.
- A prediction equation using Near Infra Red Spectroscopy can now be built because all samples have been scanned into the NIR. Using the 2002 data, we will be used to predict starch in chickpea seed samples in future years.

Seed coat thickness for 2002 and 2003

- Seed coat differed according to genotype, with the thickest coats (0.15 to 0.20 mm) found in CDC Anna, CDC Desiray, Myles and CDC Nika (all Desi chickpea). Thinner coats (0.08 to 0.09 mm) were found in the Kabuli genotypes CDC Chico, CDC Diva, CDC Xena and CDC Yuma.
- For both years of data combined, seed coat thickness was the same regardless of location (0.12 mm and 0.14 mm for Saskatoon and Swift Current, respectively).
- When the effect of seed size category was taken into account, in 2002 all seed <450 mg had significantly thicker seed coats than seed >500 mg. Coats ranged from 0.18 to 0.23 mm for the small seeds, and 0.16 to 0.11 mm for the larger seeds.
- In 2003, the dry year, less seed resources were placed in the seed coats, with coats being thinner. The pattern of small seeds having thicker coats was seen again, but thickness was less than 2002 and ranged from 0.14 to 0.15 mm for seed <375 mg. Seeds >500 mg had coats ranging from 0.10 to 0.12 mm.
- Seed coat thickness appears to be associated with market class, the Desi types having colored seed coats and thicker seed coats. As seed size increased, seed had thinner coats. In dry years, seed had thinner coats but the same pattern of small seed having the thicker coats was still evident.

Fiber analysis for 2002 and 2003

- The range in fiber was 49 to 64% for all data using the Ankom methods, which is a gross over estimation in chickpea. Hulse reviewed food science data from many sources and reported up to 13.5% crude fiber in chickpea, and up to 12% in the oligosaccharides sucrose, raffinose, stachyose and verbascose. (Hulse, J.H., *Nature, Composition and Utilization of Food Legumes. In Expanding the Production and Use of Cool season Food Legumes 77-87, Eds Muehlbauer and Kaiser, Luwer Academic Publishers, Dordrecht, 1994*).
- The reason for fiber overestimation by ADF and NDF methods is not solved at this time, but we suspect either starch or soluble carbohydrate is overlapping into the measurement, or there may be additional problems involved in the grind size. Typically the Ankom method is routinely used in fiber analysis of animal feeds and forage. Fiber in hulled chickpea seed is expected to be made up of oligosaccharides, glucans, cellulose, phenolic compounds and pigments associated with the seed coat, and structural tissue such as lignin.
- Higher concentrations of fiber (both NDF at > 62% and ADF at >60%) were found in the Desi genotypes, namely 92-073-40, CDC Desiray, and Myles (Table 10).

- Lower concentrations of fiber (< 58% NDF and <56% ADF) were found in Amit, CDC Chico, CDC Diva, CDC Xena and CDC Yuma, all Kabuli genotypes (Table 10).
- NDF concentrations were close but slightly higher than ADF values. There was little difference and both methods perform similarly for predicting fiber in chickpea.
- In both 2002 and 2003, seed in the range 51 to 300 mg had the highest fiber values of 59% and more (NDF and ADF), and 2002 seed as large as 350 mg had NDF >59%. One exception was ADF in 2003, the dry year, where fiber was about 55% and greater - slightly lower than ADF from 2002.
- In both years, the lowest fiber values were associated with the larger seed size categories, generally >500 mg. Exceptions were NDF and ADF in 2003, where lowest fiber concentrations were found in seed of 100 mg lower, that is, >400 mg.
- Even with such diverse years, small seed in the range of 50 to 250 mg have fiber concentrations in the range of 55 to 63%, regardless of ADF or NDF method. Larger seeds, in the range of 400 to 700 mg have lower fiber concentrations, typically in the range of 49 to 55%. Small seeds did have higher fiber concentrations, reflecting the Desi colored seed coat, and the higher surface area to volume ratio from a fixed weight of seed (one gram of small seed will have more seed coat than one gram of large seed). Low fiber can be selected by choosing large seed and the Kabuli market class.

Water uptake for 2002 and 2003

Water imbibition, or uptake into a seed, was quantified by two models, the Peleg model and a monomolecular model (Tables 12 to 14). The Peleg is a reciprocal model; the monomolecular model illustrates a sharp initial uptake, which plateaus off.

- The Peleg model, for both years, showed higher intercepts for CDC Anna, CDC Desiray, and CDC Nika, which were all Desi genotypes and smaller seeded (Table 12). A high intercept means a low initial seed water content. Conversely, the large seeded Kabuli genotypes CDC Diva, CDC Xena and CDC Yuma had significantly more initial water in the seed, and lower intercept values.
- The slope of the Peleg model, for both years, showed CDC Anna had the highest value compared to low slope values seen for CDC Diva, CDC Xena and CDC Yuma. A high slope value implies a slower rate of water uptake, and a low slope value implies a high rate of water uptake. The Kabuli genotypes, and the larger seeded genotypes within the Kabulis, had the more rapid water uptake.
- When looking at individual years and the effects of seed size, similar intercept values and similar slope values were seen for each year (Table 13). Small seeded genotypes (<200 mg) had intercepts

that were highest indicating lower amounts of moisture present in the eight seed measured. Genotypes with seed larger than 300 mg had lower intercept values, from 0.33 to 0.84, representing greater amounts of moisture present in eight seed. Slope values were highest for the small seeded, and lowest for the large seeded. Seed sizes with small slopes meant that such seeds took up water most rapidly.

- The Peleg model allowed us to separate, quantitatively, the ability of seed to take up water. Larger seed are more effective at water uptake, and take up water at higher rates than their small seeded counterparts. Because most of the small seeded genotypes were Kabuli, we are not able to say if the water uptake is related to market class or seed size, since both are correlated in our treatment choices.
- The Monomolecular model identified the same patterns in genotypes as the Peleg model. The Monomolecular coefficients 'a' and 'b' measure different parameters, 'a' being the final amount of water taken up by eight seed, and 'b' being the initial rate of water uptake (slope of the curve).
- The final amount of water taken up by seed for both years was greatest for CDC Diva, CDC Xena and CDC Yuma, the larger Kabulis (Table 12).
- The least amount of water taken up was by CDC Anna, CDC Desiray and Myles. Myles seed quality was poor, and Myles is a small-seeded Desi. The Peleg model could not fit data for Myles, but the Monomolecular model could (Table 12).
- Over both years, highest rates of initial water uptake ('b' coefficient) were seen for CDC Chico, CDC Diva, Myles, CDC Xena and CDC Yuma. CDC Diva, CDC Yuma and CDC Xena had the higher of the rates. Lower rates of water uptake were seen by small seed and Desis, namely CDC Desiray and CDC Nika, and CDC Anna to a lesser extent (Table 12).
- When looking at the effects of seed size class for the two years individually, small seeded chickpea, where seed was <375 mg, had lower final water taken up ('a' coefficient; Table 14). The range was 0.97 to 3.61 g of water for eight seed. Larger seeded chickpea > 500 mg had high rates of water taken up, from 4.9 to 5.7 g for eight seed.
- For initial rate of water uptake, seed with size >300 mg (>251 mg in 2002) typically had the greater rates of uptake, in the range of 0.30 to 0.41 g water per hour for eight seed (Table 14). Lower rates of water uptake were seen for small seed sizes, namely seed <200 mg for 2002, and seed <300 mg for 2003. Of interest are the same rates of water taken up by a wide range of seed (300 to 700 mg).

Conclusions

Pilot study

- For the pilot study, oil concentration differed significantly according to genotype with the highest oil concentrations were found in CDC Nika, CDC Diva and 92-073-40 (about 5.4 to 6.5%).
- Chickpea selected for large seed or larger seed size classes per genotype would also contain more oil than small seeded chickpea, but the range was small, about 4 to 6.5%.

Field study 2002 and 2003

- Largest seeded genotypes were CDC Diva, CDC Xena and CDC Yuma in both years. Small seeded genotypes were CDC Desiray, CDC Anna and Myles, with Myles being the smallest.
- Two genotypes, CDC Anna and Amit, had seed size distribution with unequal tailing to the left in 2002, meaning more small-sized seed classes. In 2003, again CDC Anna showed the same tendency, along with CDC Desiray, for more small-sized seed classes.
- Distribution towards more larger sized seed classes in 2003 was limited by drought.
- Tight or narrow seed size distributions were evident for CDC Desiray, CDC Diva and Myles in 2002, and CDC Chico, CDC Diva, CDC Yuma and CDC Xena in 2003.
- Protein concentration in genotypes differed significantly.
- Chickpea from Saskatoon and Swift Current had similar protein concentrations in 2002, but a differential in drought increased protein in 2003, and most markedly increased protein in seed from Saskatoon compared to seed from Swift Current. These protein differences were most likely associated with weather experienced during late seed filling when metabolism may be affected (protein and starch deposition) and seed size (determined by cell expansion) has already been completed.
- Seed size classes differed significantly, with larger seed tending to have having higher protein compared to smaller seed.
- Increasing seed size tended to increase protein concentration in a well-watered year, a positive finding for markets based on larger seed size. Selection of chickpea for large seed would also have higher protein concentration.

- Effects of drought increased seed protein (>26%) far more than genotype or seed size class (18.4 to 19.7%), and protein concentrations tended to be high (> 26% across the whole range of 51 to 700 mg seed size.
- Myles is unique in that it is small seeded (<350 mg), but has high protein (19.4 to 23.3%). CDC Anna has a similar range of seed size, but low protein (<18.2%). CDC Xena and CDC Yuma had consistently high protein across the range of seed size.
- Seed marketing and sourcing for high protein seed is most effective by selecting seed that has been grown under dry drought conditions, although seed may be slightly smaller compared to seed sourced from well-watered years.
- In 2002, starch ranged from 34.2% to 40.7% using the wet chemistry enzyme protocol.
- Starch in 2002 differed significantly according to genotype, with highest starch concentration found in Amit, CDC Chico, CDC Diva, CDC Xena and CDC Yuma (> 36.9%). Lower starch was found in the remaining genotypes, with CDC Anna having the least (34.2%).
- Large sized seed, and particularly Kabuli chickpea, have the larger starch concentrations.
- A prediction equation using Near Infra Red Spectroscopy can now be built because all samples have been scanned into the NIR.
- Seed coat differed according to genotype, with the thickest coats (0.15 to 0.20 mm) found in CDC Anna, CDC Desiray, Myles and CDC Nika (all Desi chickpea). Thinner coats (0.08 to 0.09 mm) were found in the Kabuli genotypes CDC Chico, CDC Diva, CDC Xena and CDC Yuma.
- Seed coat thickness appears to be associated with market class, the Desi types having colored seed coats and thicker seed coats. As seed size increased, seed had thinner coats. In dry years, seed had thinner coats but the same pattern of small seed having the thicker coats was still evident.
- When looking at the effects of seed size class for the two years individually, small seeded chickpea, where seed was <375 mg, had lower final water taken up ('a' coefficient). The range was 0.97 to 3.61 g of water for eight seed. Larger seeded chickpea > 500 mg had high rates of water taken up, from 4.9 to 5.7 g for eight seed.
- For initial rate of water uptake, seed with size >300 mg (>251 mg in 2002) typically had the greater rates of uptake, in the range of 0.30 to 0.41 g water per hour for eight seed. Lower rates of water uptake were seen for small seed sizes, namely seed <200 mg for 2002, and seed <300 mg for 2003. Of interest are the same rates of water taken up by a wide range of seed (300 to 700 mg).

- The range in fiber was 49 to 64% for all data using the Ankom methods, which is a gross over estimation in chickpea from an expected 10 to 15% range for crude fiber. The reason for fiber overestimation by ADF and NDF methods is not solved at this time.
- Higher concentrations of fiber (both NDF at > 62% and ADF at >60%) were found in the Desi genotypes, namely 92-073-40, CDC Desiray, and Myles.
- Lower concentrations of fiber (< 58% NDF and <56% ADF) were found in Kabuli genotypes.
- Small seed in the range of 50 to 250 mg had fiber concentrations in the range of 55 to 63%, regardless of ADF or NDF method. Larger seeds, in the range of 400 to 700 mg had lower fiber concentrations, typically in the range of 49 to 55%. Small seeds did have higher fiber concentrations, reflecting the Desi colored seed coat, and the higher surface area to volume ratio from a fixed weight of seed (one gram of small seed will have more seed coat than one gram of large seed). Low fiber can be selected by choosing large seed and the Kabuli market class.
- Water imbibition, or uptake into a seed, was quantified by two models, the Peleg model and a monomolecular model (Tables 12 to 14). The Peleg is a reciprocal model; the monomolecular model illustrates a sharp initial uptake, which plateaus off. The Peleg model allowed us to separate, quantitatively, the ability of seed to take up water. Larger seed are more effective at water uptake, and take up water at higher rates than their small seeded counterparts. Because most of the small seeded genotypes were Kabuli, we are not able to say if the water uptake is related to market class or seed size, since both are correlated in our treatment choices.
- Small seeded genotypes (<200 mg) had intercepts that were highest indicating lower amounts of moisture present in the eight seed measured. Genotypes with seed larger than 300 mg had lower intercept values, from 0.33 to 0.84, representing greater amounts of moisture present in eight seed. Slope values were highest for the small seeded, and lowest for the large seeded. Seed sizes with small slopes meant that such seeds took up water most rapidly.
- The Monomolecular model identified the same patterns in genotypes as the Peleg model. The Monomolecular coefficients 'a' and 'b' measure different parameters, 'a' being the final amount of water taken up by eight seed, and 'b' being the initial rate of water uptake (slope of the curve).

Information of Benefit to Producers

Drought during seed fill lowers chickpea seed size, but increases seed protein more than breeding for higher protein. Drought also decreases the thickness of the seed coat. Large seeded genotypes have lower starch, higher protein, and lower fiber. Small seeded Desi chickpea have the highest fiber concentrations.

Information of Benefit to Processing Industry

We have a data set with two locations, an excellent range of genetic material, and extensive seed size classification and yield measurement. These data have come from drought years, although plots at Swift Current in 2002 were excellent and yielded well. The data set has breadth in structure, clear patterns between seed size category and quality measurements are emerging, and many findings are very interesting and positive. Findings will be used by the CDC to breed chickpea cultivars based on quality, and results will also be of great benefit to the processing and marketing industries. Large seed size has higher protein and fat, starch and lower fiber. Fiber values are questionable, starch is within published range, and protein is moderate. In years of drought protein increases. For non-hulled chickpea, our protein levels are towards the high end. Fat concentration falls within a very narrow range of 4 to 6%, and is responsible for a poor taste (that is, not rich and flavorful). Large sized seed rapidly takes up water for food processing. We believe chickpea has tremendous potential for improved grain quality and improved nutritional value. Currently the genotypes used have quality characteristics that fall within a continuous but not overly diverse range.

Information of Benefit to CDC Chickpea Breeding Program, Univ. SK

Findings will be used by the CDC to breed chickpea cultivars based on quality. Large seed size has higher protein and fat, starch and lower fiber. Large sized seed rapidly takes up water for seedling vigor. Large sized seed typically are associated with lower seed number per unit area and the same or lower yields as smaller seeded genotypes.

PERSONNEL

Ms Kristine Krieger, Technician, Dept Plant Sciences (paid from this project)

Others who have worked on this project:

Ms Darlene Krikau, Technician, Dept Plant Sciences

Ms Nicole Lynn, Technician, Dept Plant Sciences

Ms Connie Peron

Dr. Gene Arganosa

Dr Rosalind Ball

Dr Albert Vandenberg

Dr Thomas Warkentin

EQUIPMENT

Rental of University of Saskatchewan field equipment for seeding. Rental of nutritional analysis laboratory equipment.

PROJECT DEVELOPED MATERIALS

None to date.

ACKNOWLEDGMENTS

ADF for funding 2002, 2003.

Tables 1 to 14

OIL 2001

TABLE 1. Oil concentration (% by weight) of ground seed of 10 chickpea genotypes from 2001. Data are the mean of 3 replications for bulked samples.

<i>Genotype</i>	<i>Oil (%)</i>
92-073-40	5.37 b
CDC Anna	4.68 cd
Amit	5.11 bcd
CDC Chico	5.36 bc
CDC Desiray	4.59 d
CDC Diva	5.63 b
Myles	4.47 d
CDC Nika	6.45 a
CDC Xena	5.01 bcd
CDC Yuma	5.13 bcd

§ Means followed by the same letter are not significantly different at $P < 0.05$ by Fisher's protected LSD.

TABLE 2. Oil concentration (% by weight) of chickpea seed-size classes from 2001. Data are the mean of 3 replications for bulked seed, and seed-size classes were combined over genotype.

<i>Seed-size class (mg)</i>	<i>Oil (%)</i>
101 to 125	3.68 l
126 to 150	4.14 k
151 to 175	4.27 k
176 to 200	4.68 j
201 to 225	4.99 i
226 to 250	5.02 i
251 to 275	5.24 h
276 to 300	5.35 g
301 to 325	5.50 defg
326 to 350	5.40 fgh
351 to 375	5.52 defg
376 to 400	5.50 defg
401 to 425	5.48 efg
426 to 450	5.51 defg
451 to 475	5.48 efg
476 to 500	5.64 abcde
501 to 525	5.58 bcdef
526 to 550	5.56 cdef
551 to 575	5.70 abcd
576 to 600	5.61 bcdef
601 to 625	5.82 a
626 to 650	5.57 cdef
651 to 675	5.75 abc
676 to 700	5.58 bcdef
701 to 725	5.78 ab

§ Means followed by the same letter are not significantly different at $P < 0.05$ by Fisher's protected LSD.

SEED SIZE 2002

TABLE 3. Seed-size distribution for 10 chickpea genotypes from 2002 field studies. Data are based on N=800 per genotype, from 100 randomly selected seed per plot for 4 replications and two locations, Saskatoon and Swift Current.

Genotype	Mean size (mg)*	Median size (mg)	Mode size (mg)	CV	Range of size (mg)	Skewness [†]	Kurtosis [§]
92-073-40	344 c	347	245	19.5	133-500	-0.19	-0.62
CDC Anna	213 e	207	160	23.3	109-488	1.05	2.30
Amit	253 d	249	220	19.2	144-526	0.53	1.25
CDC Chico	274 d	268	245	18.9	122-483	0.59	0.46
CDC Desiray	197 ef	196	166	19.2	100-308	0.19	-0.11
CDC Diva	499 a	497	390	20.7	110-794	0.01	-0.29
Myles	184 f	183	100	17.4	100-291	0.01	0.13
CDC Nika	348 c	348	300	17.9	100-611	0.10	0.44
CDC Xena	495 a	499	563	19.8	223-758	-0.10	-0.40
CDC Yuma	445 b	443	358	19.4	228-683	-0.07	-0.53

* Means followed by the same letter are not significantly different at $P < 0.05$ by Fisher's protected LSD.

† Skewness: degree of shift from a normal (symmetrical) distribution. Large values indicate greater deviation from a normal distribution, a positive value means the distribution is skewed to the left, a negative value means the distribution is skewed to the right.

§ Kurtosis: degree of unequal tailing of a distribution (samples falling within the extreme ranges). A positive value indicates a greater distribution in the left tail, a negative value indicates a greater distribution in the right tail.

SEED SIZE 2003

TABLE 4. Seed-size distribution for 10 chickpea genotypes from 2003 field studies. Data are based on N=800 per genotype, from 100 randomly selected seed per plot for four replications and two locations, Saskatoon and Swift Current.

Genotype	Mean size (mg)*	Median size (mg)	Mode size (mg)	CV	Range of size (mg)	Skewness [†]	Kurtosis [§]
92-073-40	-	-	-	-	-	-	-
CDC Anna	236 e	232	193	22.1	107-609	0.94	3.92
Amit	-	-	-	-	-	-	-
CDC Chico	249 d	248	217	15.7	134-399	0.14	0.13
CDC Desiray	193 f	194	148	17.5	100-371	0.29	0.95
CDC Diva	451 a	452	457	15.9	155-628	-0.23	0.17
Myles	193 f	193	204	15.6	106-335	0.13	0.44
CDC Nika	316 c	320	328	16.6	135-545	0.05	0.52
CDC Xena	452 a	457	400	15.7	222-614	-0.31	-0.10
CDC Yuma	407 b	412	450	16.9	202-593	-0.24	-0.15

* Means followed by the same letter are not significantly different at $P < 0.05$ by Fisher's protected LSD.

† Skewness: degree of shift from a normal (symmetrical) distribution. Large values indicate greater deviation from a normal distribution, a positive value means the distribution is skewed to the left, a negative value means the distribution is skewed to the right.

§ Kurtosis: degree of unequal tailing of a distribution (samples falling within the extreme ranges). A positive value indicates a greater distribution in the left tail, a negative value indicates a greater distribution in the right tail.

SEED SIZE AT LOCATIONS IN 2003

TABLE 5. Mean seed size (mg) for 10 chickpea genotypes from 2003 field studies. Data are based on N=800 per genotype, from 100 randomly selected seed per plot for four replications and two locations, Saskatoon and Swift Current.

<i>Genotype</i>	<i>Saskatoon size (mg)</i>	<i>Swift Current size (mg)</i>
92-073-40	-	-
CDC Anna	234 a	237 a
Amit	-	-
CDC Chico	252 a	246 a
CDC Desiray	178 b	209 a
CDC Diva	435 b	466 a
Myles	184 b	202 a
CDC Nika	289 b	343 a
CDC Xena	430 b	474 a
CDC Yuma	367 b	447 a

*Means followed by the same letter for a row-wise comparison (genotype) are not significantly different at $P < 0.05$ by Fisher's protected LSD. LSD is 6 mg.

PROTEIN FOR 2002 AND 2003, AND 2002 STARCH

TABLE 6. Protein concentration (% by weight) of full samples for 10 chickpea genotypes from 2002 and 2003 field studies. Data are the mean of four replications and two locations, Saskatoon and Swift Current for both years combined, and 2002 only for starch.

<i>Genotype</i>	<i>2002 and 2003</i>	<i>2002</i>
	<i>Protein (%)</i>	<i>Starch (%)</i>
92-073-40	18.6 d*	35.0 c
CDC Anna	20.5 c	34.2 c
Amit	18.4 d*	38.1 abc
CDC Chico	23.1 a	36.9 abc
CDC Desiray	21.7 b	35.2 c
CDC Diva	23.0 a	41.6 a
Myles	23.4 a	36.2 c
CDC Nika	22.1 b	36.4 bc
CDC Xena	23.2 a	40.7 ab
CDC Yuma	23.3 a	38.9 abc

§ Means followed by the same letter in a column are not significantly different at $P < 0.05$ by Fisher's protected LSD.

* 2002 data only for protein for 92-073-40 and Amit.

PROTEIN FOR 2002 AND 2003, AND 2002 STARCH

TABLE 7. Seed protein concentration and starch concentration (%) of chickpea seed-size classes from 2002 and 2003 field studies. Data are the mean of 10 genotypes, four replications and two locations, Saskatoon and Swift Current, for each year.

<i>Seed-size class (mg)</i>	<i>2002 Protein concentration (%)</i>	<i>2003 Protein concentration (%)</i>	<i>2002 Starch concentration (%)</i>
51 to 150	19.1 bc	26.3 b	33.8 cd
151 to 200	18.5 de	26.3 b	32.8 d
201 to 300	18.5 de	26.6 ab	38.1 abcd
251 to 350	18.4 e	26.5 ab	36.2 bcd
301 to 400	18.8 cde	26.7 ab	35.2 bcd
351 to 375	19.2 abc	26.6 ab	37.2 abcd
401 to 450	19.1 bc	26.7 ab	39.9 ab
451 to 500	19.0 bcd	26.7 ab	37.6 abcd
501 to 550	19.2 abc	27.2 a	41.5 a
551 to 600	19.2 abc	26.7 ab	37.4 abcd
601 to 650	19.4 ab	26.4 ab	38.8 abc
651 to 700	19.7 a	-	42.5 a

§ Means followed by the same letter in a column are not significantly different at $P < 0.05$ by Fisher's protected LSD.

SEED COAT THICKNESS, NDF AND ADF FOR 2002 AND 2003

TABLE 10. Seed coat thickness (mm), and fiber concentration (% by weight) measured by neutral detergent fiber (NDF) and acid detergent fiber (ADF) methods and of full samples for 10 chickpea genotypes from 2002 and 2003 field studies combined. Data are the mean of four replications and two locations, Saskatoon and Swift Current, for both years.

<i>Genotype</i>	<i>2002 and 2003</i>	<i>2002 and 2003</i>	<i>2002 and 2003</i>
	<i>Seed coat</i>	<i>NDF</i>	<i>ADF</i>
	<i>thickness (mm)</i>	<i>(%)</i>	<i>(%)</i>
92-073-40	-	62.0 ab	61.9 a
CDC Anna	0.15 ab	59.9 bc	57.7 bc
Amit	-	57.5 cde	57.1 cd
CDC Chico	0.08 c	56.2 de	53.9 def
CDC Desiray	0.17 a	62.0 ab	60.4 ab
CDC Diva	0.09 c	55.1 e	53.2 ef
Myles	0.20 a	63.7 a	61.5 a
CDC Nika	0.17 a	58.2 cd	56.1 cde
CDC Xena	0.10 bc	54.6 e	52.0 f
CDC Yuma	0.10 bc	56.0 de	54.0 def

§ Means followed by the same letter in a column are not significantly different at $P < 0.05$ by Fisher's protected LSD.

SEED COAT THICKNESS, NDF AND ADF FOR 2002 AND 2003

TABLE 11. Seed protein concentration (%) of chickpea seed-size classes from 2002 field studies. Data are the mean of 10 genotypes, 4 replications and two locations, Saskatoon and Swift Current.

<i>Seed-size class (mg)</i>	<i>2002 Seed coat Thickness (mm)</i>	<i>2003 Seed coat Thickness (mm)</i>	<i>2002 NDF (%)</i>	<i>2003 NDF (%)</i>	<i>2002 ADF (%)</i>	<i>2003 ADF (%)</i>
51 to 150	0.21 ab	0.15 ab	62.4 a	63.4 a	62.4 a	58.2 a
151 to 200	0.21 ab	0.14 abc	60.4 b	61.0 b	60.0 b	55.8 b
201 to 300	0.23 a	0.15 a	59.7 b	59.8 b	59.4 b	54.9 b
251 to 350	0.23 a	0.14 ab	59.1 b	57.4 cd	58.8 bc	52.9 c
301 to 400	0.20 abc	0.14 abc	57.6 c	56.2 de	57.5 c	52.1 cd
351 to 375	0.19 abc	0.14 abc	56.3 cd	58.0 c	56.1 d	52.0 cd
401 to 450	0.18 abcd	0.12 bcd	56.1 d	56.2 de	55.8 d	51.0 e
451 to 500	0.17 bcd	0.12 bcd	55.6 de	55.5 ef	55.5 de	50.6 e
501 to 550	0.14 de	0.10 cd	54.5 ef	53.9 f	54.2 ef	50.4 e
551 to 600	0.16 bcd	0.10 d	54.2 f	54.8 ef	54.1 ef	49.9 e
601 to 650	0.16 cde	0.11 d	53.9 f	54.0 f	53.7 f	49.9 e
651 to 700	0.11 e		54.3 ef	-	54.3 ef	-

§ Means followed by the same letter in a column are not significantly different at $P < 0.05$ by Fisher's protected LSD.

WATER UPTAKE FOR 2002 AND 2003, PELEG & MONOMOLECULAR MODEL

TABLE 12. Water uptake, indicated by the intercept and slope terms of the Peleg model, and by model terms 'a' (plateau) and 'b' (initial slope) of the monomolecular model. Data are the mean of terms from models fitted over eight seed from each sample (four replications and two locations, Saskatoon and Swift Current, for two years for each genotype).

Genotype	2002 and 2003	2002 and 2003	2002 and 2003	2002 and 2003
	<i>Peleg</i>	<i>Peleg</i>	<i>Monomolecular</i>	<i>Monomolecular</i>
	<i>intercept</i>	<i>slope</i>	<i>a</i>	<i>b</i>
	(hr / g water uptake)	(1 / g water uptake)	(g water uptake)	(g water uptake / hr)
92-073-40*	-	-	-	-
CDC Anna	3.84 a	0.65 a	1.54 de	0.15 bc
Amit*	-	-	-	-
CDC Chico	1.03 b	0.36 bc	2.99 bc	0.29 ab
CDC Desiray	5.02 a	0.39 b	1.32 de	0.08 c
CDC Diva	0.29 b	0.21 c	4.37 a	0.41 a
Myles*	-	-	0.84 e	0.24 abc
CDC Nika	5.36 a	0.36 bc	2.19 cd	0.09 bc
CDC Xena	0.33 b	0.21 c	4.44 a	0.34 a
CDC Yuma	0.29b	0.24 bc	3.96 ab	0.42 a

§ Means followed by the same letter in a column are not significantly different at $P < 0.05$ by Fisher's protected LSD.

* 92-073-40 and Amit were not grown in 2003, so no data are included. Myles seed was poor and did not fit the Peleg model.

WATER UPTAKE FOR 2002 AND 2003, PELEG MODEL

TABLE 13. Water uptake for chickpea seed-size classes from 2002 and 2003 field studies, indicated by the intercept and slope terms of the Peleg model. Data are the mean of terms from models fitted over eight seed from each sample (four replications and two locations, Saskatoon and Swift Current, for two years over all genotypes).

Seed-size class (mg)	2002	2003	2002	2003
	Peleg	Peleg	Peleg	Peleg
	Intercept	Intercept	Slope	Slope
	(hr / g water uptake)	(hr / g water uptake)	(1 / g water uptake)	(1 / g water uptake)
51 to 150	2.58 ab	4.37 a	0.75 a	0.71 a
151 to 200	3.33 a	3.55 ab	0.47 b	0.57 b
201 to 300	1.69 bc	0.72 c	0.40 c	0.44 c
251 to 350	1.02 cd	1.45 bc	0.35 c	0.35 d
301 to 400	0.72 cd	0.84 c	0.29 d	0.29 e
351 to 375	0.69 d	0.53 c	0.28 de	0.25 ef
401 to 450	0.47 d	0.43 c	0.23 ef	0.23 fg
451 to 500	0.40 d	0.34 c	0.20 fg	0.21 fgh
501 to 550	0.38 d	0.32 c	0.19 fg	0.18 ghi
551 to 600	0.38 d	0.33 c	0.19 fg	0.18 hi
601 to 650	0.44 d	0.33 c	0.18 fg	0.16 i

§ Means followed by the same letter in a column are not significantly different at $P < 0.05$ by Fisher's protected LSD.

WATER UPTAKE FOR 2002 AND 2003, MONOMOLECULAR MODEL

TABLE 14. Water uptake for chickpea seed-size classes from 2002 and 2003 field studies, indicated by model terms 'a' (plateau) and 'b' (initial slope) of the monomolecular model. Data are the mean of terms from models fitted over eight seed from each sample (four replications and two locations, Saskatoon and Swift Current, for two years over all genotypes).

Seed-size class (mg)	2002 Monomolecular a (g water uptake)	2003 Monomolecular a (g water uptake)	2002 Monomolecular b (g water uptake / hr)	2003 Monomolecular b (g water uptake / hr)
51 to 150	0.97 h	0.96 j	0.23 cd	0.16 f
151 to 200	1.78 g	1.54 i	0.22 d	0.20 e
201 to 300	2.41 f	1.92 h	0.29 bcd	0.20 e
251 to 350	2.61 ef	2.64 g	0.37 a	0.27 d
301 to 400	3.09 de	3.24 f	0.34 abcd	0.30 cd
351 to 375	3.44 d	3.61 e	0.31 abcd	0.32 bc
401 to 450	4.01 c	4.05 d	0.32 abcd	0.37 a
451 to 500	4.53 bc	4.39 c	0.36 ab	0.39 a
501 to 550	4.90 ab	5.01 b	0.32 abcd	0.35 ab
551 to 600	4.89 ab	5.12 b	0.35 abc	0.33 bc
601 to 650	5.26 a	5.72 a	0.31 abcd	0.31 cd
651 to 700	5.40 a	-	0.41 a	-

§ Means followed by the same letter in a column are not significantly different at $P < 0.05$ by Fisher's protected LSD.

PROTEIN 2002

TABLE 8. Protein concentration for seed from seed-size classes for 10 Chickpea genotypes in 2002. Means are based on four replications and averaged over two locations, Saskatoon and Swift Current.

Seed-size class (mg)	92-073-40*	Amit	CDC Anna	CDC Chico*	CDC Desiray*	CDC Diva*	Myles*	CDC Nika*	CDC Xena	CDC Yuma
51 to 150			18.2 a		18.7 b		19.4 b			
151 to 200		18.7 a	16.9 a	16.4 d	18.8 b		19.7 b			
201 to 300	17.4 d	18.5 a	16.9 a	18.1 c	19.2 b		20.5 b	17.9 b		
251 to 350	17.7 cd	18.5 a	17.2 a	18.6 bc	20.3 a		23.3 a	18.3 ab		18.8 a
301 to 400	18.2 bc	18.7 a	17.2 a	19.6 ab		18.5 d		18.7 ab	19.8 a	19.1 a
351 to 375	18.7 ab	19.3 a		20.2 a		19.2 bc		19.1 a	19.6 a	19.3 a
401 to 450	19.3 a					19.1 c		19.1 a	19.1 a	19.1 a
451 to 500						19.2 bc		19.0 a	18.9 a	19.2 a
501 to 550						19.2 bc			19.0 a	19.5 a
551 to 600						19.0 cd			19.4 a	19.6 a
601 to 650						19.7 ab			19.0 a	19.5 a
651 to 700						20.0 a			19.4 a	

* § Means followed by the same letter within a column (genotype) are not significantly different at *P<0.05 by Fishers protected LSD.

PROTEIN 2003

TABLE 9. Protein concentration for seed from seed-size classes for 10 Chickpea genotypes in 2003. Means are based on four replications and averaged over two locations, Saskatoon and Swift Current.

Seed-size class (mg)	CDC Anna*	CDC Chico	CDC Desiray*	CDC Diva	Myles	CDC Nika*	CDC Xena*	CDC Yuma
51 to 150	24.2 a	27.8 a	26.0 a		27.5 a			
151 to 200	24.1 ab	28.0 a	-		26.9 a	27.9 a		30.3 a
201 to 300	24.0 ab	27.8 a	25.7 a	29.3 a	28.2 a	25.2 bc		30.1 a
251 to 350	23.9 ab	28.5 a	25.7 a	26.5 a	25.9 a	25.0 bc	28.2 a	28.5 a
301 to 400	24.1 ab	28.4 a	23.9 b	27.4 a		24.9 bc	27.9 ab	27.4 a
351 to 375	23.4 ab			26.9 a		25.3 b	27.7 ab	27.3 a
401 to 450	22.2 b			26.8 a		24.1 c	27.8 ab	27.2 a
451 to 500				27.0 a		22.9 d	27.5 abc	26.8 a
501 to 550				26.6 a			27.3 bcd	27.1 a
551 to 600				25.9 a			26.7 cd	27.7 a
601 to 650				25.4 a			26.6 d	
651 to 700								

* § Means followed by the same letter within a column (genotype) are not significantly different at *P<0.05 by Fishers protected LSD.

